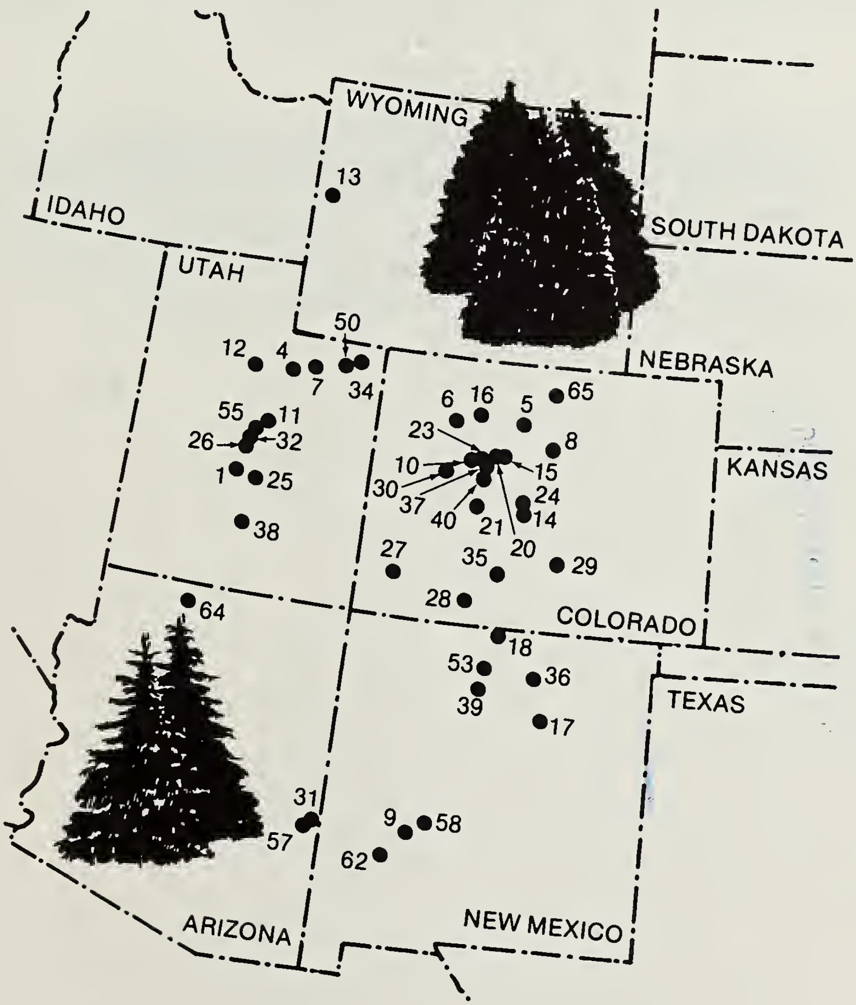
Genetic Variation in Blue Spruce: A Test of Populations in Nebraska

David F. Van Haverbeke



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Abstract

Analyses of 43 blue spruce populations, at age 12 (9 years in the field) revealed significant differences among populations for survival, height, vigor, crown diameter, frost injury, and foliage color. Use of regions increases the probability of locating better seed sources, but high variability among individual populations within regions limits their value in specifying where better seed sources can be collected. Phenotypes should be selected in best stands within regions.

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Management Implications

The Great Plains is a region with few native evergreen species. One of the objectives of tree improvement research in this region is to introduce, test, and identify adapted seed sources of coniferous species for use in Great Plains windbreak, environmental improvement and esthetic plantings.

Blue spruce (*Picea pungens* Engelm.), because of its desirable foliage color and symmetry, is a highly valued species in the northern half of the United States and in Canada for landscaping and Christmas tree production. Because it is cold-hardy, drought-resistant, and long-lived, blue spruce is also a desirable species for use in shelterbelt plantings, especially in the eastern part of the central and northern Great Plains and in the Prairie Provinces of Canada. Identification of blue spruce seed sources that are adapted to particular planting sites would increase the number of evergreen species suitable for planting in the North American prairie-plains.

Introduction

Blue spruce is native to the central Rocky Mountain region of the United States (fig. 1). Stands of this species extend from northcentral Montana, south through southern and western Wyoming and eastern Idaho, Utah, northern central and eastern Arizona, southern, western and northern New Mexico, and central Colorado (Little 1971 and 1979, Jones and Rietveld 1974, Hanover 1975, Strong 1978). Blue spruce usually grows at montane elevations of 1,800 to 2,600 m, occasionally reaching into the subalpine zone up to 3,100 m in the southernmost part of its range (Fechner 1980). Trees grow singly, or in small groups, along the banks of streams and in broad, cool, humid and grassy valleys. Blue spruce is a relatively slow growing conifer that eventually attains great size and is long-lived. Its native habitats are characterized by cool summers and dry winters, although snowfall is usually high at most sites. The species is drought-resistant and cold-tolerant.

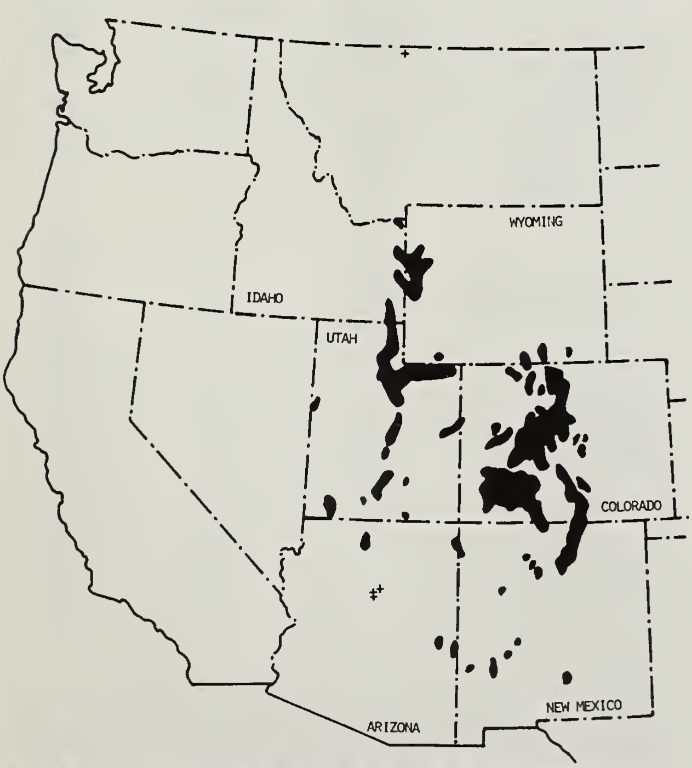

Figure 1.—Natural range of blue spruce (after Little 1971 and Hanover 1975).

Blue spruce may grow in association with the closely related Engelmann spruce (*Picea engelmannii* Parry ex. Engelm.); however, Engelmann spruce is typically a subalpine (2,750 to 3,350 m elevation) species. Although the two species are usually isolated from each other, sometimes they are associated in scattered zones of altitudinal overlap throughout much of the blue spruce range (Fowler and Roche 1975). Hybridization either does not occur (Daubenmire 1972), or occurs infrequently because of various pre-fertilization incompatibilities (Fechner and Clark 1969, Kossuth and Fechner 1973).

The plantation reported on here is part of a regional test of blue spruce populations for which 2-year nursery performances (Hanover and Reicosky 1972), and five-year field performances in Canada (Canada Dep. Reg. Econ. Exp. 1979) and in northern United States and Canada (Bongarten 1978) were reported. Nine-year field (12 years from sowing) performances of the populations in the Nebraska plantations are reported here.

Material and Methods

Seedling stock for this test originated from seed collected in the fall of 1969 from more than 400 trees throughout the natural range of blue spruce (Hanover and Reicosky 1972). The seed was sown in single-tree lots, in an East Lansing, Mich. nursery, in 1970. In 1972, the 2+0 stock was shipped to 17 cooperators throughout the northcentral region of the United States and Canada. The seedlings were field-planted in the spring of 1973 as 2+1 stock, following transplanting by individual cooperators. Prior to shipment, progenies of individual trees sampled from the same locale were combined to form populations. Material for the Nebraska test contained 43 populations consisting of seedlings from 1 to 22 parent trees per population (fig. 2, table 1).

The plantation is located approximately 90 km east of Lincoln, in southeast Nebraska (41°00′ N latitude, 96°52′ W longitude), on a silty clay loam soil derived

from loess with a gently sloping, southeast-facing slope. The growing season averages 170 days, and the mean annual precipitation is 760 mm, of which approximately 75% falls during the growing season. The elevation is 305 m.

Seedlings were machine-planted in a randomized complete block design of 4-tree linear plots with 5 replications. Seedlings were spaced 2.4 m apart within rows 4.5 m apart.

Survival (%), height and crown diameter (m), vigor (mean annual height increment for the last 4 years), frost injury (scale of 0 to 3, with 0 = light, 3 = heavy), and winter foliage color (scale of 0 to 8) were recorded in fall 1981 and evaluated. Foliage color was qualified utilizing Ridgway's (1912) color standards and nomenclature (Appendix).

Data were analyzed on the basis of: (1) all 43 populations as individuals and (2) a partitioning of the 43 populations into six regional groups based on latitude and longitude. The latter analysis was intended to detect possible regions of superior performance, wherein, each group was considered as a "population" and the populations within each group as a sample of those available. This yielded an analysis of regional differences based on an error variance formed from the variation among populations in each regional group.

Results

Survival

Survival percentages among the 43 blue spruce populations after 9 field seasons (12 years from sowing)

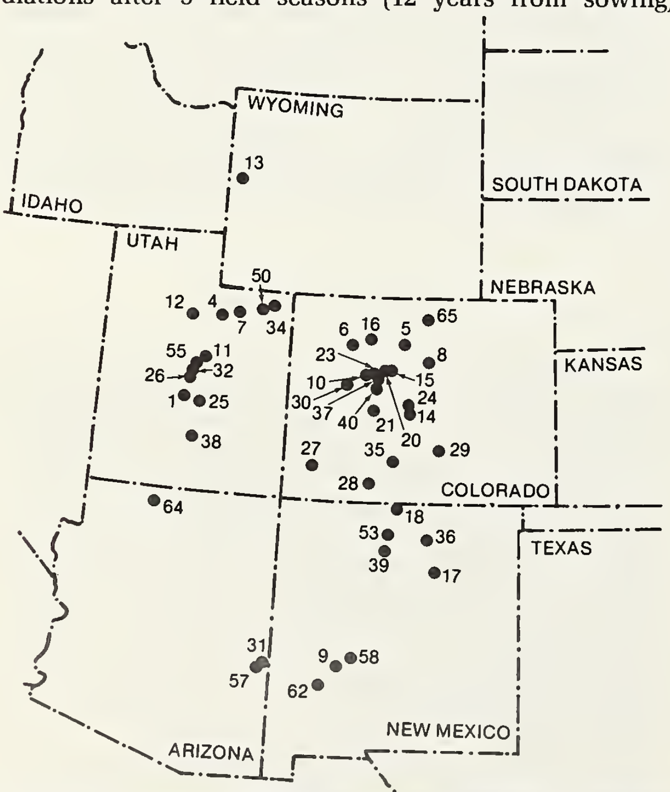

Figure 2.—Locations of blue spruce populations tested in eastern Nebraska (after Hanover 1975).

Table 1.—Identities and survival of blue spruce populations in eastern Nebraska

Regional groups	Pop. no.	Parent trees in pop.	Survival
		no.	percent
I	4	6	85.0
Wyoming	7	4	75.0
No. Utah	12	8	90.0
	13	18	80.0
	34	1	25.0
	50	8	80.0
Sub-total & X̄		45	72.5
II	5	6	60.0
No. Colorado	6	7	75.0
	8	11	80.0
	16	7	80.0
	65	20	70.0
Sub-total & X̄		51	73.0
III	1	4	70.0
Central Utah	11	10	85.0
	25	4	55.0
	26	2	80.0
	32	5	75.0
	38	8	85.0
	55	1	90.0
Sub-total & X̄		34	77.1
IV	10	13	65.0
Central	14	10	70.0
Colorado	15	9	70.0
	20	1	70.0
	21	3	85.0
	23	1	50.0
	24	10	80.0
	30	2	50.0
	37	8	60.0
	40	12	60.0
Sub-total & X̄		69	66.0
V	17	5	61.1
So. Colorado	18	1	35.0
No. Arizona	27	9	85.0
No. New Mexico	28	7	65.0
	29	9	30.0
	35	13	90.0
	36	9	45.0
	39	11	60.0
	53	10	65.0
	64	7	65.0
Sub-total & X̄		81	60.1
VI	9	3	65.0
So. Arizona	31	22	80.0
So. New Mexico	57	2	65.0
	58	6	60.0
	62	4	70.0
Sub-total & X̄		37	68.0
Grand total & X̄		317	68.4

averaged 68.4%, ranging from 25% to 90% (table 1). Chi-square analysis revealed significant differences in percent survival among the populations ($X^2 = 94.5$) ($P > 0.05$) (table 2A). The 43 populations could be partitioned into three segments, with populations in the highest and

Table 2.—Analysis of survival in 43 populations and 6 regional groupings of blue spruce populations in an eastern Nebraska test

Source of variation	Chi-square analysis df	X^2
(A) Among populations	42	94.5*
Among segments	2	80.8*
Within segment A (25-35%)	2	0.5
Within segment B (45-70%)	21	10.5
Within segment C (75-90%)	17	3.8
(B) Among populations	42	94.5*
Among regions	5	13.7*
Within region I (Wyoming, No. Utah)	5	26.3*
II (No. Colorado)	4	2.6
III (Cen. Utah)	6	7.8
IV (Cen. Colorado)	9	11.0
V (So. Colorado, No. Arizona, No. New Mexico)	9	31.0*
VI (So. Arizona, So. New mexico)	4	2.1

**Denotes significance at the 5% level of probability*

lowest surviving segments being considered homogeneous and separate. Populations 18, 29, and 34 comprised the lowest surviving segment, and populations 4, 6, 7, 8, 11, 12, 13, 16, 21, 24, 26, 27, 31, 32, 35, 38, 50, and 55 comprised the highest surviving segment (fig. 2, table 1). Survival was only weakly correlated with latitude (r = 0.38).

A partitioning of the 43 populations into six regional groups suggested a trend of higher survival percentages in the northern (I and II) and westernmost (III) groups (table 1). Average survival percentages ranged from 77% in group III (central Utah) to 60% in group V (southern Colorado, northern Arizona and northern New Mexico. Chi-square analysis indicated significant differences among the regional group means, but also attributed much of the variation to individual populations within the groups (table 2B).

Height and Vigor

After two field seasons (in 1975), the seedlings averaged 30.8 cm in height, with a range of 23.2 to 52.4 cm. Six of the 10 tallest populations (27, 31, 53, 57, 62, and 64) were from southwestern Colorado, Arizona, and New Mexico (fig. 2). The remaining 4 populations (10, 20, 40, and 55) were from mid-latitude locations in central Colorado and central Utah. These 10 populations have maintained their height superiority throughout the 9-year field test period, and were among the tallest 20 populations in 1981 (table 3 and fig. 3). The four curves in figure 3 illustrate the pattern of height development of groups of populations with statistically similar heights.

The 11 shortest populations at age 2 in the field (1975) occurred from northeast Utah and northern Colorado to northcentral New Mexico. By 1981, however, the most northerly of these shortest populations had separated into a significantly taller southern group (17, 18, and 29) and a significantly shorter northern group (23, 65, 16, 30, 36, 5, 38, and 34) (figs. 2 and 3). This latter group of 8 populations were the shortest 8 populations at age 9 in 1981 (table 3).

Analysis of tree height revealed significant differences among the populations, separating a relatively tall group of mid-latitude (10, 40, and 55) and southern-latitude (9, 17, 27, 28, 39, and 53) (table 3). Populations 64, 31, and 62 were taller than all others, however. The relationship between tree height and latitude, was relatively weak (r = 0.30).

Analysis of the six regional groups showed significant separation among the groups, with trees from southern Arizona and southern New Mexico being significantly taller than trees from Wyoming, Utah, northern and central Colorado (table 4).

Several Arizona and New Mexico populations (9, 17, 31, 39, 53, 62, and 64) were among the most vigorous, although only slightly more so than a series of central and southern Colorado populations (10, 27, 28, and 40) (table 3). Tree vigor, not surprisingly, was strongly correlated with tree height (r = 0.92). A similar north and west to south trend of increasing tree vigor was reflected in the regional groups with regional populations from southern Colorado, Arizona, and New Mexico being the most vigorous (table 4). The southern population 57, within regional groups VI, is an exception (table 3).

Crown Diameter

Tree crowns were wider in some populations from southern Colorado (27 and 28), Arizona (31 and 64), New Mexico (9, 53, and 62), central and northern Colorado (10, and 40), and central Utah (55) (table 3). Width of crowns was also strongly correlated with tree height (r = 0.82), but weakly related to latitude (r = 0.27) and longitude (r = 0.01).

A north-south but nonsignificant trend of increasing crown width was present in the regional groups (table 4).

Frost Injury

Six populations, four of southern origin (27, 36, 57, and 58), were identified as more susceptible to frost injury (table 3); but the relationships among frost injury resulting from early flushing, and latitude and longitude were weak. Analysis of frost injury on the regional basis showed real differences in susceptibility; but although the more northerly regional populations were less susceptible to winter injury, there was no regular pattern (table 4).

Table 3.—Mean data and cluster analysis groupings of means[1] for height, vigor, crown diameter, frost injury, and foliage color of 43 blue spruce populations in an eastern Nebraska test

Pop. ID	Characteristics				
	Height	Vigor	Crown diameter	Frost injury	Foliage color
	m	*no.*	*m*	*no.*	*no.*
34	1.0 a	0.5 a	0.8 a	1.4 b	2.0 a
38	1.2 a	0.6 a	1.0 b	1.4 b	3.4 b
5	1.2 a	0.6 a	1.1 b	1.6 b	6.1 c
36	1.2 a	0.6 a	1.1 b	2.2 c	4.4 b
30	1.3 a	0.6 a	1.0 b	1.7 b	4.5 b
16	1.3 a	0.7 a	1.1 b	1.7 b	4.0 b
65	1.3 a	0.6 a	1.1 b	1.6 b	2.2 a
23	1.3 a	0.7 a	1.0 b	1.7 b	4.0 b
11	1.3 a	0.6 a	1.2 c	1.8 b	3.0 b
25	1.4 a	0.6 a	1.1 b	1.3 a	3.8 b
7	1.4 a	0.6 a	1.1 b	1.7 b	1.9 a
15	1.4 a	0.7 a	1.1 b	1.7 b	3.4 b
32	1.4 a	0.6 a	1.1 b	1.4 b	2.2 a
12	1.4 b	0.7 a	1.1 c	1.3 a	4.2 b
24	1.4 b	0.7 a	1.2 c	1.8 b	4.6 b
35	1.4 b	0.8 b	1.1 c	2.0 c	5.1 c
1	1.4 b	0.7 a	1.2 c	1.5 b	4.1 b
18	1.4 b	0.7 b	1.2 c	1.7 b	5.1 c
21	1.4 b	0.7 b	1.2 c	1.8 b	2.2 a
4	1.5 b	0.7 a	1.2 c	1.2 a	3.1 b
29	1.5 b	0.8 b	1.2 c	1.8 b	6.0 c
37	1.5 b	0.7 a	1.3 c	1.8 b	3.8 b
26	1.5 b	0.7 a	1.2 c	1.4 b	3.2 b
13	1.5 b	0.7 b	1.2 c	1.1 a	2.3 a
57	1.5 b	0.6 a	1.0 b	1.9 c	5.7 c
14	1.5 b	0.8 b	1.2 c	1.8 b	2.8 b
50	1.5 b	0.7 b	1.2 c	1.5 b	3.5 b
8	1.5 b	0.8 b	1.2 c	1.6 b	2.9 b
58	1.6 b	0.7 b	1.2 c	2.0 c	5.7 c
20	1.6 b	0.8 b	1.2 c	2.1 c	3.6 b
6	1.6 b	0.7 b	1.3 c	1.5 b	3.4 b
39	1.6 c	0.8 c	1.3 c	1.5 b	4.2 b
28	1.6 c	0.8 c	1.5 d	1.6 b	4.5 b
17	1.7 c	0.9 c	1.3 c	1.3 a	5.3 c
10	1.7 c	0.8 c	1.4 d	1.6 b	5.5 c
9	1.7 c	0.8 c	1.5 d	1.7 b	6.5 c
55	1.7 c	0.7 b	1.6 d	1.1 a	4.1 b
27	1.7 c	0.8 c	1.5 d	2.1 c	7.1 c
40	1.7 c	0.8 c	1.4 d	1.4 b	4.0 b
53	1.7 c	0.9 c	1.5 d	1.9 b	7.1 c
64	1.9 d	0.9 c	1.4 d	1.3 a	4.8 c
62	1.9 d	0.9 c	1.6 d	1.1 a	1.0 a
31	2.1 d	1.0 c	1.6 d	1.6 b	3.4 b

[1]*Means without a letter in common are different at the 5% level according to the Cluster Analysis Method for Grouping Means in the Analysis of Variance (Scott and Knott 1974). Means of equal value may be separated due to rounding off.*

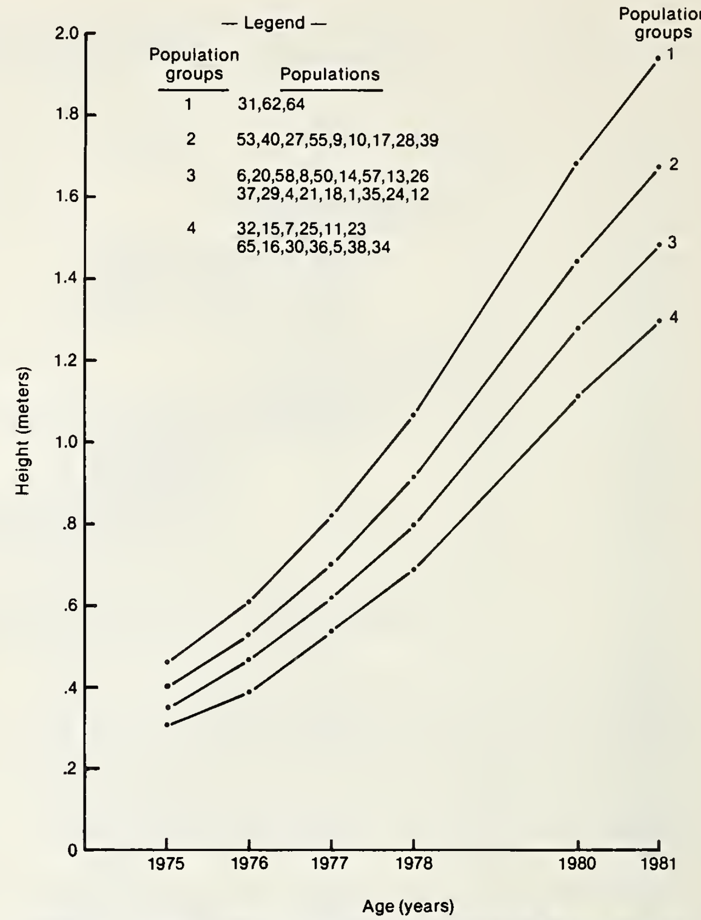

Figure 3.—Height curves of statistically similar blue spruce populations in an eastern Nebraska plantation. (See Table 3 for individual population mean heights and levels of significance.)

Foliage Color

Twelve populations were identified as exhibiting bluer foliage color than others (table 3). Ten of these (9, 17, 18, 27, 29, 35, 53, 57, 58, and 64) were from the southern half of the blue spruce range; populations 5 and 10 were from central and northcentral Colorado (fig. 2). Although the relationship between foliage color and latitude was weak (r = 0.20), there was significant separation among the regional groups with a pattern of increasing blueness toward the southern portions of the range, especially in group V (southern Colorado, northern Arizona, and northern New Mexico) (table 4).

Discussion

Although survival varied considerably among the populations, a multiple comparison analysis did not reveal any statistically pairwise differences. This was attributed to a condition common to many population, seed source, provenance, and progeny tests; i.e., large numbers of entries with relatively small sample sizes per entry. However, the data were partitioned into components according to differences among population group means and to differences within each group, and the populations were separated into three groups, of

Table 4.—Mean data and multiple range tests[1] for height, vigor, crown diameter, frost injury, and foliage color of 6 regional groupings of 43 blue spruce populations in eastern Nebraska test

Characteristics									
Height		Vigor		Crown diameter		Frost injury		Foliage color	
	m		*no.*		*m*		*no.*		*no.*
I[2]	1.25 a	I	0.66 a	II	1.13 a	I	1.37 a	I	3.0 a
II	1.40 a	III	0.66 a	I	1.16 a	III	1.45 a	II	3.7 a
III	1.43 a	II	0.67 a	III	1.19 a	II	1.63 a-b	III	3.7 a
IV	1.49 a	IV	0.72 a-b	IV	1.19 a	VI	1.69 a-b	IV	3.9 a
V	1.58 a-b	V	0.79 b	V	1.31 a	V	1.75 b	VI	4.5 a-b
VI	1.77 b	VI	0.79 b	VI	1.37 a	IV	1.77 b	V	5.4 b

[1]*Means followed by a common letter are not different at the 5% level (Tukey's Multiple Range Analysis of Pairwise Differences).*

[2] *I = Wyoming and northern Utah*
II = Northern Colorado
III = Central Utah
IV = Central Colorado
V = Southern Colorado, northern Arizona, and northern New Mexico
VI = Southern Arizona and southern New Mexico

which the lowest and highest surviving groups were considered separate and homogeneous. There were also differences among regional group means; but no clear geographic pattern in survival was apparent.

There were important differences among the 43 populations for the other 5 evaluation criteria. Correlation of these characteristics with the geographic variables of latitude and longitude was generally weak, however, reflecting considerable variability among the populations throughout the range of the species.

Partitioning the 43 populations into the six regional groups indicated significant differences among the groups and revealed a series of directional trends in characteristic expression. These trends point to somewhat higher survival in the northern populations, and greater height growth and vigor, more frost injury, and bluer foliage color in the southern populations. The inconsistencies between height and vigor, especially in populations 17, 29, 35, 55, and 57, may indicate populations whose performances may change drastically in the future (table 3).

Dawson and Rudolf (1966) tested seven blue spruce seed lots collected from stands in Wyoming, Utah, Colorado, Arizona, at Denbigh, North Dakota. They reported that at age 13 (5 years in the field), a source from the Wyoming-Utah border exceeded the other six sources in survival, height growth, resistance to frost damage, and crown diameter. Although statistically significant differences among populations were few in this analysis, collection of seed from the best stands throughout Colorado and Utah would seem advisable for use in the northern Great Plains and the Canadian Prairie Provinces, where winter injury to southern origins of blue spruce may be likely. Cram (1968) reported that blueness of foliage color was transmittable to as many as 50% of the progeny of some locally grown blue spruce trees in Saskatchewan, Canada.

Conclusions

With minor variations, the data reported here confirm the developmental patterns reported by Hanover and Reicosky (1972), Bongarten (1978) and Canada Department of Regional Economic Development (1979). These data show that populations in the southern portion of the species range tend to have trees exhibiting more of the characteristics commonly desired in the species; e.g., faster growth and more blueness in foliage color. Individual populations within regions are quite variable, however, making regions of limited value in specifying where better seed can be collected. The probability of locating trees, exhibiting desirable characteristics for Great Plains plantings, would appear to be increased by selecting within stands containing high percentages of desirable phenotypes in southern Colorado, Arizona, and New Mexico.

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APPENDIX

Table A-1.—Assignment of qualitative identifications to blue spruce foliage color, after Ridgway (1912)

Rating number	Color name	Plate number	Color or Hue number	Tone
0	Courge Green	XVII	25′	i
1	Parrot Green	VI	31	k
2	Chromium Green	XXXII	31′′	i
3	Deep Dull Yellow Green (1)	XXXII	31′′	k
4	Grass Green	VI	33	k
5	Pois Green	XLI	29′′′	i
6	Pistachio Green	XLI	33′′′	–
7	Gnaphalium Green	XLVII	29′′′′	d
8	Deep Bluish Glaucous	XLII	37′′′	d

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Mountains

Southwest

Great
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The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526